Department of Mathematical Sciences

Prasad Tetali, Department Head

Dejan Slepčev, Associate Head

Jason Howell, Director of Undergraduate Studies

Location: Wean Hall 6113
www.math.cmu.edu (http://www.math.cmu.edu)

Mathematics provides much of the language and quantitative underpinnings of the natural and social sciences, and mathematical scientists have been responsible for the development of many of the most commonly used tools in business management as well as for laying the foundation for computational and computer science. The name of the Department of Mathematical Sciences reflects its tradition of outstanding research and teaching of applicable mathematics relating to these areas. Indeed, the Department contains highly ranked research groups in Applied Mathematics, Discrete Mathematics, Logic, and Mathematical Finance. These research strengths are reflected in the variety of options that the Department provides for its undergraduate majors.

The Department offers a B.S. degree in Mathematical Sciences. Concentrations within the degree include Mathematical Sciences, Operations Research and Statistics, Statistics, Discrete Mathematics and Logic, and Computational and Applied Mathematics.

The Mathematical Sciences concentration is the least structured of our programs, in recognition of the wide variety of interests that can be productively coupled with the study of mathematical sciences. It can be an appropriate choice for students planning for graduate study in mathematics or seeking to design their curriculum to take advantage of the many opportunities for a second major from another department in the University.

The Operations Research and Statistics Concentration prepares students to enter the area of operations research. Mathematicians with a background in operations research are especially valuable in such diverse activities as project planning, production scheduling, market forecasting and finance. Such applications are found in virtually all industrial and governmental settings.

The Statistics Concentration prepares students to contribute to a wide variety of research areas. Applications range from experimental design and data analysis in the physical and social sciences, medicine and engineering, to modeling and forecasting in business and government, to actuarial applications in the financial and insurance industries. This is also a useful second major for students planning for graduate study and research in subject areas requiring a strong statistical background.

The Discrete Mathematics and Logic Concentration provides a background in discrete mathematics, mathematical logic, and theoretical computer science. This concentration prepares the student to do research in these and related fields, or to apply their ideas elsewhere.

Finally, the Computational and Applied Mathematics Concentration provides the background needed to support the computational and mathematical analysis needs of a wide variety of businesses and industries and is well suited to students with an interest in the physical sciences and engineering.

The Department places great emphasis on the advising of students. This is critical if students are to make the most of their years at the University. Students are urged to work carefully with their advisor and other faculty to formulate their degree programs. Study abroad is encouraged, and an interested student should investigate the opportunities available in the Undergraduate Options (http://coursecatalog.web.cmu.edu/aboutcmu/undergraduateoptions/) section of the catalog.

Special Options

The Department offers special opportunities for the exceptionally well-prepared and intellectually ambitious student. These options are available to students from any department in the University.

Matrix Theory and Vector Analysis

For selected freshmen entering the University, the department offers the Fall/Spring sequence of Matrix Theory (21-242) and Vector Analysis (21-269), which include a rigorous introduction to proofs and abstract mathematics. Typically, a student choosing this sequence has mastered the operational aspects of high school mathematics and now seeks a deeper conceptual understanding.

- Matrix Theory (21-242) is an honors version of Matrices and Linear Transformations (21-241).
- Vector Analysis (21-269) is an honors version of Multidimensional Calculus (21-268).

Admission to Matrix Theory (21-242) is based on a placement test taken at the start of the freshman year. Admission to Vector Analysis (21-269) is based on a student's performance in Matrix Theory (21-242), and on other courses taken in the Fall semester.

Mathematical Studies

The sequence of undergraduate honors courses continues with the Mathematical Studies courses, aimed primarily at sophomores. These highly demanding courses provide excellent preparation for graduate study, with many of the participants taking graduate courses as early as their junior year. Students will be expected to master material at a high level of abstraction, and to work on very challenging problems. The typical enrollment of about 15 students allows for close contact with the instructors.

- 21-235 Mathematical Studies Analysis I is an honors version of 21-355 Principles of Real Analysis I.
- 21-237 Mathematical Studies Algebra I is an honors version of 21-373 Algebraic Structures.
- 21-236 Mathematical Studies Analysis II is an honors version of 21-356 Principles of Real Analysis II.
- 21-238 Mathematical Studies Algebra II) is an honors version of 21-341 Linear Algebra.

Admission to Mathematical Studies is by invitation. Interested students should apply during the Spring of their freshman year. Applicants are not absolutely required to have taken 21-242 Matrix Theory or 21-269 Vector Analysis, and may be admitted on the basis of exceptionally strong performance in non-honors mathematics courses.

It is possible to take only the Algebra courses or only the Analysis courses. Admission to 21-236 Mathematical Studies Analysis II requires a grade of B or better in 21-235 Mathematical Studies Analysis I, and similarly, admission to 21-238 Mathematical Studies Algebra II requires a grade of B or better in 21-237 Mathematical Studies Algebra I.

Interdisciplinary Programs

Several interdisciplinary options enable a student to combine mathematics with other disciplines.

- The Bachelor of Science and Arts (http://coursecatalog.web.cmu.edu/intercollegeprograms/bxaintercollege/#bachelorofscienceandartsdegreeprogram) program allows a student to combine mathematics with study in any of the five schools in the College of Fine Arts.
- The Bachelor of Science in Mathematics and Economics (http://coursecatalog.web.cmu.edu/schools-colleges/tepper/undergraduateeconomicsprogram/#bsineconomicsandmathematicalsciences) is a flexible program which allows students to develop depth in both fields of study. Note: for students whose home college is Dietrich College, this major is known as the Bachelor of Science in Economics and Mathematical Sciences.
- Finally, a joint program with the Heinz College of Public Policy and Management and the Tepper School of Business leads to the degree Bachelor of Science in Computational Finance (http://coursecatalog.web.cmu.edu/intercollegeprograms/#bachelorofscienceincomputationalfinance).

Curriculum

For each concentration, we provide a list of the requirements and a suggested schedule that takes prerequisites into account. A Mathematical Sciences, Computer Science, Physics, Statistics Elective refers to any course from the Departments of Mathematical Sciences, Computer Science, Physics, or Statistics and Data Science, respectively, satisfying the following restrictions: a mathematical sciences course must be at the 21-300 level or above or 21-270 or 21-292, a computer science course must be at the 15-200 level or above, a physics course must be at the 33-300 level or above, and a statistics course must be at the 36-300 level or above and have at least 36-225 as a prerequisite.

Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's

advisor, the Director of Undergraduate Studies in Mathematical Sciences, or the Department Head of Mathematical Sciences.

A student preparing for graduate study should also consider undertaking independent work. The Department offers 21-410 Research Topics in Mathematical Sciences and 21-599 Undergraduate Reading and Research for this purpose. At most a total of 9 units of 21-410/21-599 can be applied toward the Depth Elective requirement. This requires permission of both the advisor and the department.

Mathematical Sciences majors are required to complete an introductory computer science course, either 15-110 or 15-112. Students who plan to take further computer science courses must complete 15-112.

A Nontechnical Elective refers to a course in the Dietrich College of Humanities and Social Sciences requirements as described in the catalog section for the Mellon College of Science. A course listed as an Elective is a free elective with the only restriction that the maximum total of ROTC, StuCo, and Physical Education units that will be accepted for graduation is nine.

For a list of courses required for all MCS students see First Year for Science Students (http://coursecatalog.web.cmu.edu/schools-colleges/melloncollegeofscience/#firstyearforsciencestudents).

B.S. in Mathematical Sciences (Mathematical Sciences)

This program is the most flexible available to our majors. The flexibility to choose eight electives within the major plus seven humanities courses and seven free electives allows the student to design a program to suit his or her individual needs and interests. By default, students must fulfill all the requirements of the catalog of the year they entered CMU. Students who wish to be considered for a subsequent catalog may submit a request to the Director of Undergraduate Studies. The requirements for the Mathematics Degree are:

Mathematical Sciences Courses (required)

The alternative courses 21-242, 21-261, and 21-268 (or 21-269) are particularly recommended for a student planning to pursue graduate work.

Courses		Units
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-201	Undergraduate Colloquium	1
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-259	Calculus in Three Dimensions	9
or 21-266	Vector Calculus for Computer Scientists	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-325	Probability	9
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
21-341	Linear Algebra	9
21-355	Principles of Real Analysis I	9-10
or 21-455	Intermediate Real Analysis I	
21-356	Principles of Real Analysis II	9-10
or 21-456	Intermediate Real Analysis II	
21-373	Algebraic Structures	9
		115-117

Forty-five units of (required) Mathematical Sciences electives (at the 21-300 level or above or 21-270 or 21-292).

Twenty-seven units of (required) Mathematical Sciences (at the 21-300 level or above or 21-270 or 21-292, or Computer Science (at the 15-200 level or above), or Physics (at the 33-300 level or above), or Statistics (must be at the 36-300 level or above and have at least 36-225 as a prerequisite) electives.

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units)

Mathematical Sciences Electives for Students Intending Graduate Studies

Students preparing for graduate study in mathematics should consider the following courses as Mathematical Sciences electives, choosing among them according to the desired area of graduate study. Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's academic advisor, the Director of Undergraduate Studies in Mathematical Sciences, or the Department Head of Mathematical Sciences.

Courses		Units
21-301	Combinatorics	9
21-360	Differential Geometry of Curves and Surfaces	9
21-371	Functions of a Complex Variable	9
21-374	Field Theory	9
21-441	Number Theory	9
21-465	Topology	9
21-470	Selected Topics in Analysis	9
21-476	Introduction to Dynamical Systems	9
21-484	Graph Theory	9
21-602	Introduction to Set Theory I	12
21-603	Model Theory I	12
21-610	Algebra I	12
21-620	Real Analysis	6
21-621	Introduction to Lebesgue Integration	6
21-630	Ordinary Differential Equations	12
21-632	Introduction to Differential Equations	12
21-640	Introduction to Functional Analysis	12
21-651	General Topology	12
21-660	Introduction to Numerical Analysis I	12
21-701	Discrete Mathematics	12
21-720	Measure and Integration	12
21-721	Probability	12
21-723	Advanced Real Analysis	12
21-737	Probabilistic Combinatorics	12
21-738	Extremal Combinatorics	12

Note that courses 21-600 and above carry graduate credit. Courses at the 600 level are designed as transitional courses to graduate study. A student preparing for graduate study should also consider undertaking independent work. The Department offers 21-410 Research Topics in Mathematical Sciences and 21-599 Undergraduate Reading and Research for this purpose.

Courses 21-700 and above can be used with the permission of both the advisor and the department.

Suggested Schedule for students without AP credit

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
38-101	EUREKA!: Discovery and Its Impact	6
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
xx-xxx	Technical Breadth Requirement	9
		47

Spring		Units
15-110	Principles of Computing	10
or 15-112	Fundamentals of Programming and Computer Science	
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-122	Integration and Approximation	10
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		50

Sophomore Year

Fall		Units
21-201	Undergraduate Colloquium	1
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-268	Multidimensional Calculus	10
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
xx-xxx	Free Elective	9
		47

Spring		Units
21-261	Introduction to Ordinary Differential Equations	10
21-373	Algebraic Structures	9
38-230	ENGAGE in Wellness: Looking Inward	1
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		47

Junior Year

Fall		Units
21-355	Principles of Real Analysis I	9
or 21-455	Intermediate Real Analysis I	
21-325	Probability	9
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
38-330	ENGAGE in Wellness: Looking Outward	1
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
xx-xxx	Free Elective	9
		46

Spring		Units
21-341	Linear Algebra	9
21-356	Principles of Real Analysis II	9
or 21-456	Intermediate Real Analysis II	
21-xxx	Mathematical Sciences Elective	9
xx-xxx	Science and Society Course	6
xx-xxx	Cultural/Global Understanding Elective	9
		42

Senior Year

Fall		Units
21-xxx	Mathematical Sciences Elective	9
21-xxx	Mathematical Sciences Elective	9
38-110	ENGAGE in Service [1]	1
38-220	ENGAGE in the Arts [1]	2
38-430	ENGAGE in Wellness: Looking Forward	1
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		40

Spring		Units
21-xxx	Mathematical Sciences Elective	9
21-xxx	Mathematical Sciences Elective	9
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Minimum number of units required for degree: 360

Suggested Schedule for Students with AP Credit

Freshman Year

Fall		Units
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
38-101	EUREKA!: Discovery and Its Impact	6
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
xx-xxx	Technical Breadth Requirements	9
		49

Spring		Units
15-110	Principles of Computing	10
or 15-112	Fundamentals of Programming and Computer Science	
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-268	Multidimensional Calculus	10
or 21-269	Vector Analysis	
xx-xxx	Nontechnical Elective	9
		38

Sophomore Year

Fall		Units
21-325	Probability	9
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
21-373	Algebraic Structures	9
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
xx-xxx	Free Elective	9
		45

Spring		Units
21-261	Introduction to Ordinary Differential Equations	10
21-355	Principles of Real Analysis I	9
or 21-455	Intermediate Real Analysis I	
38-230	ENGAGE in Wellness: Looking Inward	1
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		38

Junior Year

Fall		Units
21-356	Principles of Real Analysis II	9
or 21-456	Intermediate Real Analysis II	
21-xxx	Mathematical Sciences Elective	9
38-330	ENGAGE in Wellness: Looking Outward	1
xx-xxx	Cultural/Global Understanding Course	9
xx-xxx	Free Elective	9
		37

Spring		Units
21-341	Linear Algebra	9
21-xxx	Mathematical Sciences Elective	9
xx-xxx	Science and Society Course	6
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		42

Senior Year

Fall		Units
21-xxx	Mathematical Sciences Elective	9
21-xxx	Mathematical Sciences Elective	9
38-110	ENGAGE in Service [1]	1
38-220	ENGAGE in the Arts [1]	2
38-430	ENGAGE in Wellness: Looking Forward	1
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9

xx-xxx	Free Elective	9
		49

Spring		Units
21-xxx	Mathematical Sciences Elective	9
21-xxx	Mathematical Sciences Elective	9
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Minimum number of units required for degree: 360

B.S. in Mathematical Sciences (Operations Research and Statistics)

An operations research professional employs quantitative and computational skills toward enhancing the function of an organization or process. Students choosing this concentration will develop problem-solving abilities in mathematical and statistical modeling and computer-based simulation in areas such as network design, transportation scheduling, allocation of resources and optimization. In addition to courses in mathematics and statistics, a basic background in economics and accounting is included. Since problems in business and industry are often solved by teams, the curriculum typically includes group projects. Students choosing this concentration may not pursue an additional minor in Statistics in the Dietrich College of Humanities and Social Sciences College. By default, students must fulfill all the requirements of the catalog of the year they entered CMU. Students who wish to be considered for a subsequent catalog may submit a request to the Director of Undergraduate Studies.

The requirements for the concentration in Operations Research and Statistics are:

Mathematical Sciences Courses (required)

The alternative courses 21-242, 21-261, and 21-268 (or 21-269) are particularly recommended for a student planning to pursue graduate work.

Courses		Units
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-201	Undergraduate Colloquium	1
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-259	Calculus in Three Dimensions	9
or 21-266	Vector Calculus for Computer Scientists	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-292	Operations Research I	9
21-369	Numerical Methods	12
21-393	Operations Research II	9
		100

Statistics Courses (required)

Courses		Units
21-325	Probability	9
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
36-226	Introduction to Statistical Inference	9
36-401	Modern Regression	9
36-402	Advanced Methods for Data Analysis	9
36-410	Introduction to Probability Modeling	9
		45

Economics, Business, and Computer Science Courses (required)

Courses		Units
15-110	Principles of Computing	10
70-122	Introduction to Accounting	9
73-102	Principles of Microeconomics	9
73-103	Principles of Macroeconomics	9
73-230	Intermediate Microeconomics	9
or 73-240	Intermediate Macroeconomics	
		46

Depth Electives (required)

Forty-five units of (required) depth electives, to be chosen from the list below. The courses 21-355 and 21-455 are particularly recommended for a student planning to pursue graduate work. Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's academic advisor, the Director of Undergraduate Studies in Mathematical Sciences, or the Department Head of Mathematical Sciences.

Courses		Units
10-301	Introduction to Machine Learning (Undergrad)	12
or 10-315	Introduction to Machine Learning (SCS Majors)	
10-605	Machine Learning with Large Datasets	12
15-122	Principles of Imperative Computation	10
15-150	Principles of Functional Programming	10
15-210	Parallel and Sequential Data Structures and Algorithms	12
21-270	Introduction to Mathematical Finance	9
21-301	Combinatorics	9
21-321	Interactive Theorem Proving	9
21-341	Linear Algebra	9
21-355	Principles of Real Analysis I	9-10
or 21-455	Intermediate Real Analysis I	
21-356	Principles of Real Analysis II	9
or 21-456	Intermediate Real Analysis II	
21-366	Topics in Applied Mathematics	9
21-370	Discrete Time Finance	9
21-373	Algebraic Structures	9
21-377	Monte Carlo Simulation for Finance	9
21-378	Mathematics of Fixed Income Markets	9
21-420	Continuous-Time Finance	9
21-484	Graph Theory	9
36-461	Special Topics: Statistical Methods in Epidemiology	9
36-462	Special Topics: Methods of Statistical Learning	9
36-463	Special Topics: Multilevel and Hierarchical Models	9
36-464	Special Topics: Applied Multivariate Methods	9
70-371	Operations Management	9
70-460	Mathematical Models for Consulting	9
70-471	Supply Chain Management	9

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units)

Note that 73-102, 73-103, 73-230, and 73-240 satisfy requirements from the MCS general education core.

Suggested Schedule

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
38-101	EUREKA!: Discovery and Its Impact	6
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3

xx-xxx	Technical Breadth Requirement	9
		47

Spring		Units
15-110	Principles of Computing	10
or 15-112	Fundamentals of Programming and Computer Science	
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-122	Integration and Approximation	10
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		50

Sophomore Year

Fall		Units
21-201	Undergraduate Colloquium	1
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-259	Calculus in Three Dimensions	9
or 21-266	Vector Calculus for Computer Scientists	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
73-102	Principles of Microeconomics	9
xx-xxx	Technical Breadth Requirement	9
		37

Spring		Units
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-292	Operations Research I	9
38-230	ENGAGE in Wellness: Looking Inward	1
70-122	Introduction to Accounting	9
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		46

Junior Year

Fall		Units
21-369	Numerical Methods	12
21-325	Probability	9
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
73-103	Principles of Macroeconomics	9
xx-xxx	Depth Elective	9
38-330	ENGAGE in Wellness: Looking Outward	1
		40

Spring		Units
36-226	Introduction to Statistical Inference	9
36-410	Introduction to Probability Modeling	9
73-230	Intermediate Microeconomics	9
or 73-240	Intermediate Macroeconomics	
xx-xxx	Depth Elective	9
xx-xxx	Science and Society Course	6
xx-xxx	Cultural/Global Understanding Course	9
		51

Senior Year

Fall		Units
21-393	Operations Research II	9
36-401	Modern Regression	9
xx-xxx	Depth Elective	9
38-110	ENGAGE in Service [1]	1
38-220	ENGAGE in the Arts [1]	2
38-430	ENGAGE in Wellness: Looking Forward	1
xx-xxx	Nontechnical Elective	9
xx-xxx	Free Elective	9
		49

Spring		Units
36-402	Advanced Methods for Data Analysis	9
xx-xxx	Depth Elective	9
xx-xxx	Depth Elective	9
xx-xxx	Nontechnical Elective	9
xx-xxx	Free Elective	9
		45

Minimum number of units required for degree: 360

B.S. in Mathematical Sciences (Statistics)

Statistics is concerned with the process by which inferences are made from data. Statistical methods are essential to research in a wide variety of scientific disciplines. For example, principles of experimental design that assist chemists in improving their yields also help poultry farmers grow bigger chickens. Similarly, time series analysis is used to better understand radio waves from distant galaxies, hormone levels in the blood, and concentrations of pollutants in the atmosphere. This diversity of application is an exciting aspect of the field, and it is one reason for the current demand for well-trained statisticians.

The courses 15-259 Probability and Computing and 36-226 Introduction to Statistical Inference taken in the Junior year serve as the basis for all further statistics courses. The course 21-325 is a more mathematical alternative to 15-259.

The Statistics Concentration is jointly administered by the Department of Mathematical Sciences and the Department of Statistics and Data Science. The Department of Statistics and Data Science considers applications for the master's program from undergraduates in the Junior year. Students who are accepted are expected to finish their undergraduate studies, using some electives in the Senior year to take courses recommended by the Department of Statistics and Data Science. This will ensure a strong background to permit completion of the master's program in one year beyond the baccalaureate. Students choosing this concentration may not pursue an additional minor in Statistics in the Dietrich College of Humanities and Social Sciences. By default, students must fulfill all the requirements of the catalog of the year they entered CMU. Students who wish to be considered for a subsequent catalog may submit a request to the Director of Undergraduate Studies. The requirements for the Statistics Concentration are:

Mathematical Sciences Courses (required)

The alternative courses 21-242, 21-261, and 21-268 (or 21-269) are particularly recommended for a student planning to pursue graduate work.

Courses		Units
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-201	Undergraduate Colloquium	1
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-259	Calculus in Three Dimensions	9
or 21-266	Vector Calculus for Computer Scientists	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-292	Operations Research I	9
21-369	Numerical Methods	12
21-393	Operations Research II	9
		100

Statistics Courses (required)

Courses		Units
21-325	Probability	9

or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
36-226	Introduction to Statistical Inference	9
36-401	Modern Regression	9
36-402	Advanced Methods for Data Analysis	9
36-410	Introduction to Probability Modeling	9
		45

Economics and Computer Science Courses (required)

Courses		Units
15-112	Fundamentals of Programming and Computer Science	12
15-122	Principles of Imperative Computation	10
73-102	Principles of Microeconomics	9
		31

Depth Electives (required)

Forty-five units of (required) depth electives, including at least nine units in statistics, to be chosen from the list below. The courses 21-355 and 21-455 are particularly recommended for a student planning to pursue graduate work. Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's academic advisor, the Director of Undergraduate Studies in Mathematical Sciences, or the Department Head of Mathematical Sciences.

Courses		Units
10-301	Introduction to Machine Learning (Undergrad)	12
or 10-315	Introduction to Machine Learning (SCS Majors)	
10-605	Machine Learning with Large Datasets	12
15-150	Principles of Functional Programming	10
15-210	Parallel and Sequential Data Structures and Algorithms	12
21-270	Introduction to Mathematical Finance	9
21-321	Interactive Theorem Proving	9
21-341	Linear Algebra	9
21-355	Principles of Real Analysis I	9-10
or 21-455	Intermediate Real Analysis I	
21-356	Principles of Real Analysis II	9
or 21-456	Intermediate Real Analysis II	
21-366	Topics in Applied Mathematics	9
21-370	Discrete Time Finance	9
21-373	Algebraic Structures	9
21-377	Monte Carlo Simulation for Finance	9
21-378	Mathematics of Fixed Income Markets	9
21-420	Continuous-Time Finance	9
21-484	Graph Theory	9
36-461	Special Topics: Statistical Methods in Epidemiology	9
36-462	Special Topics: Methods of Statistical Learning	9
36-463	Special Topics: Multilevel and Hierarchical Models	9
36-464	Special Topics: Applied Multivariate Methods	9

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units)

Note that 73-102 satisfies a requirement from the MCS core.

Suggested Schedule

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
38-101	EUREKA!: Discovery and Its Impact	6
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
xx-xxx	Life/Physical Sciences Course	9
		47

Spring		Units
15-112	Fundamentals of Programming and Computer Science	12
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-122	Integration and Approximation	10
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Physical/Life Sciences Course	9
		52

Sophomore Year

Fall		Units
21-201	Undergraduate Colloquium	1
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-259	Calculus in Three Dimensions	9
or 21-266	Vector Calculus for Computer Scientists	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
73-102	Principles of Microeconomics	9
xx-xxx	Technical Breadth Requirements	9
xx-xxx	Nontechnical Elective	9
		46

Spring		Units
15-122	Principles of Imperative Computation	10
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-292	Operations Research I	9
38-230	ENGAGE in Wellness: Looking Inward	1
xx-xxx	Nontechnical Elective	9
xx-xxx	Free Elective	9
		47

Junior Year

Fall		Units
21-369	Numerical Methods	12
21-325	Probability	9
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
xx-xxx	Depth Elective	9
xx-xxx	Depth Elective	9
38-330	ENGAGE in Wellness: Looking Outward	1
xx-xxx	Nontechnical Elective	9
		49

Spring		Units
36-226	Introduction to Statistical Inference	9
36-410	Introduction to Probability Modeling	9
xx-xxx	Depth Elective	9
xx-xxx	Science and Society Course	6
xx-xxx	Cultural/Global Understanding Course	9
		42

Senior Year

Fall		Units
21-393	Operations Research II	9
36-401	Modern Regression	9
xx-xxx	Depth Elective	9
38-110	ENGAGE in Service [1]	1
38-220	ENGAGE in the Arts [1]	2
38-430	ENGAGE in Wellness: Looking Forward	1

xx-xxx	Nontechical Elective	9
		40
Spring		Units
36-402	Advanced Methods for Data Analysis	9
xx-xxx	Depth Elective	9
xx-xxx	Depth Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Minimum number of units required for degree: 360

B.S. in Mathematical Sciences (Discrete Mathematics and Logic)

Discrete mathematics is the study of finite and countable structures and algorithms for the manipulation and analysis of such structures, while mathematical logic is the study of axiomatic systems and their mathematical applications. Both are flourishing research areas and have close ties with computer science.

The Discrete Mathematics and Logic Concentration provides a firm background in discrete mathematics and mathematical logic, together with the elements of theoretical computer science. It prepares the student to pursue research in these fields, or to apply their ideas in the many disciplines (ranging from philosophy to hardware verification) where such ideas have proved relevant. By default, students must fulfill all the requirements of the catalog of the year they entered CMU. Students who wish to be considered for a subsequent catalog may submit a request to the Director of Undergraduate Studies.

The requirements for the Discrete Mathematics and Logic Concentration are:

Mathematical Sciences and Computer Science Courses (required)

The alternative course 21-242 is particularly recommended for a student planning to pursue graduate work. Students who plan to pursue graduate study in mathematical logic are strongly advised to take 21-300 Basic Logic.

Courses		Units
15-122	Principles of Imperative Computation	10
15-150	Principles of Functional Programming	10
15-210	Parallel and Sequential Data Structures and Algorithms	12
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-201	Undergraduate Colloquium	1
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-300	Basic Logic	9
or 15-317	Constructive Logic	
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-301	Combinatorics	9
21-341	Linear Algebra	9
21-355	Principles of Real Analysis I	9-10
or 21-455	Intermediate Real Analysis I	
21-373	Algebraic Structures	9
		129-130

Computer Science electives (required)

Any two courses at the 300 level or above. The following are specifically suggested:

15-312	Foundations of Programming Languages	12
15-451	Algorithm Design and Analysis	12
15-453	Formal Languages, Automata, and Computability	9

Students pursuing this concentration who minor in Computer Science must take two additional Computer Science courses at the 300 level or above to avoid excessive double counting.

Mathematical Sciences Electives (required)

Sixty-three units of mathematical sciences electives, to be chosen from list 1 and 2 below, including at least twenty-seven units chosen from list 1. Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's academic advisor, the Director of Undergraduate Studies in Mathematical Sciences, or the Department Head of Mathematical Sciences.

List 1 (Discrete Mathematics and Logic Electives)

Courses		Units
15-259	Probability and Computing	12
21-321	Interactive Theorem Proving	9
21-325	Probability	9
21-329	Set Theory	9
21-374	Field Theory	9
21-400	Intermediate Logic	9
21-441	Number Theory	9
21-484	Graph Theory	9
21-602	Introduction to Set Theory I	12
21-603	Model Theory I	12
21-610	Algebra I	12
21-701	Discrete Mathematics	12
80-405	Game Theory	9
80-411	Proof Theory	9
80-413	Category Theory	9

List 2 (General Mathematics Electives)

Courses		Units
21-259	Calculus in Three Dimensions	9-10
or 21-266	Vector Calculus for Computer Scientists	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9-10
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-270	Introduction to Mathematical Finance	9
21-292	Operations Research I	9
21-356	Principles of Real Analysis II	9
or 21-456	Intermediate Real Analysis II	
21-366	Topics in Applied Mathematics	9
21-369	Numerical Methods	12
21-370	Discrete Time Finance	9
21-371	Functions of a Complex Variable	9
21-393	Operations Research II	9
21-420	Continuous-Time Finance	9
21-470	Selected Topics in Analysis	9
21-476	Introduction to Dynamical Systems	9
21-410	Research Topics in Mathematical Sciences	9

Any graduate course in mathematics at the 600 and 700 level not included in List 1.

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units)

Suggested Schedule

Freshman Year

Fall		Units
15-112	Fundamentals of Programming and Computer Science	12
21-120	Differential and Integral Calculus	10
38-101	EUREKA!: Discovery and Its Impact	6
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
xx-xxx	Life/Physical Sciences Course	9
		49
Spring		Units
15-122	Principles of Imperative Computation	10

21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
xx-xxx	Technical Breadth Requirement	9
		51

Sophomore Year

Fall		Units
15-150	Principles of Functional Programming	10
21-201	Undergraduate Colloquium	1
21-268	Multidimensional Calculus	10
or 21-269	Vector Analysis	
21-301	Combinatorics	9
21-373	Algebraic Structures	9
xx-xxx	Nontechnical Elective	9
		48

Spring		Units
15-210	Parallel and Sequential Data Structures and Algorithms	12
38-230	ENGAGE in Wellness: Looking Inward	1
xx-xxx	Discrete Math/Logic Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		49

Junior Year

Fall		Units
15-xxx	Computer Science Elective	9
21-300	Basic Logic	9
or 15-317	Constructive Logic	
21-355	Principles of Real Analysis I	9
or 21-455	Intermediate Real Analysis I	
38-330	ENGAGE in Wellness: Looking Outward	1
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		46

Spring		Units
15-xxx	Computer Science Elective	9
21-341	Linear Algebra	9
xx-xxx	Science and Society Course	6
xx-xxx	Nontechnical Elective	9
xx-xxx	Cultural/Global Understanding Course	9
		42

Senior Year

Fall		Units
xx-xxx	Discrete Math/Logic Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	Mathematics Elective	9
38-110	ENGAGE in Service [1]	1
38-220	ENGAGE in the Arts [1]	2
38-430	ENGAGE in Wellness: Looking Forward	1
xx-xxx	Free Elective	9
		40

Spring		Units
xx-xxx	Discrete Math/Logic Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	Free Elective	9
		36

Minimum number of units required for degree: 360

B.S. in Mathematical Sciences (Computational and Applied Mathematics)

This concentration is designed to prepare students for careers in business or industry which require significant analytical, computational and problem solving skills. It also prepares students with interest in computational and applied mathematics for graduate school.

The students in this concentration develop skills to choose the right framework to quantify or model a problem, analyze it, simulate and in general use appropriate techniques for carrying the effort through to an effective solution. The free electives allow the student to develop an interest in a related area by completing a minor in another department, such as Engineering Studies, Economics, Information Systems or Business Administration. By default, students must fulfill all the requirements of the catalog of the year they entered CMU. Students who wish to be considered for a subsequent catalog may submit a request to the Director of Undergraduate Studies.

The requirements for the Computational and Applied Mathematics Concentration are:

Mathematical Sciences Courses (required)

The alternative courses 21-242, 21-261, and 21-268 (or 21-269) are particularly recommended for a student planning to pursue graduate work.

Courses		Units
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-201	Undergraduate Colloquium	1
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-259	Calculus in Three Dimensions	9
or 21-266	Vector Calculus for Computer Scientists	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-325	Probability	9
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
21-355	Principles of Real Analysis I	9-10
or 21-455	Intermediate Real Analysis I	
21-369	Numerical Methods	12
21-469	Computational Introduction to Partial Differential Equations	12
		112-113

Depth Electives (required)

Students must take twenty-seven units of depth electives, to be chosen from the list below. Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's academic advisor, the Director of Undergraduate Studies in Mathematical Sciences, or the Department Head of Mathematical Sciences.

Courses		Units
10-301	Introduction to Machine Learning (Undergrad)	12
or 10-315	Introduction to Machine Learning (SCS Majors)	
21-270	Introduction to Mathematical Finance	9
21-292	Operations Research I	9
21-344	Numerical Linear Algebra	9
21-380	Introduction to Mathematical Modeling	9
21-435	Applied Harmonic Analysis	9

Computer Science Courses (required)

Courses		Units
15-122	Principles of Imperative Computation	10

Mathematics Electives (required)

Students must take 27 units either from the three remaining courses from the depth electives or from the list below:

Courses		Units
21-321	Interactive Theorem Proving	9
21-341	Linear Algebra	9
21-356	Principles of Real Analysis II	9
or 21-456	Intermediate Real Analysis II	
21-366	Topics in Applied Mathematics	9
21-370	Discrete Time Finance	9
21-371	Functions of a Complex Variable	9
21-373	Algebraic Structures	9
21-377	Monte Carlo Simulation for Finance	9
21-378	Mathematics of Fixed Income Markets	9
21-393	Operations Research II	9
21-420	Continuous-Time Finance	9
21-470	Selected Topics in Analysis	9
21-476	Introduction to Dynamical Systems	9
21-484	Graph Theory	9
21-620	Real Analysis	6
21-621	Introduction to Lebesgue Integration	6
21-630	Ordinary Differential Equations	12
21-632	Introduction to Differential Equations	12
21-640	Introduction to Functional Analysis	12
21-651	General Topology	12
21-660	Introduction to Numerical Analysis I	12
21-690	Methods of Optimization	12
21-720	Measure and Integration	12
21-721	Probability	12
21-723	Advanced Real Analysis	12
21-732	Partial Differential Equations I	12
21-832	Partial Differential Equations II	12

Students must take nine additional units of Mathematical Sciences (at the 21-300 level or above or 21-270 or 21-292), or Computer Science (at the 15-200 level or above), or Physics (at the 33-300 level or above), or Statistics (must be at the 36-300 level or above and have at least 36-225 as a prerequisite) electives.

21-366 Topics in Applied Mathematics and 21-470 Selected Topics in Analysis have content that varies from year to year. These courses can be taken more than once (with permission).

Note that courses 21-600 and above carry graduate credit. 600-level courses are designed as transitional courses to graduate study.

A student preparing for graduate study should also consider undertaking independent work. The Department offers 21-410 Research Topics in Mathematical Sciences and 21-599 Undergraduate Reading and Research for this purpose.

Courses 21-700 and above can be used with the permission of both the advisor and the department.

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units).

Students not in MCS are required to take 15-110 Principles of Computing (10 units).

Suggested Schedule

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
38-101	EUREKA!: Discovery and Its Impact	6
76-101	Interpretation and Argument	9
xx-xxx	Technical Breadth Requirement	9
		44

Spring		Units
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-228	Discrete Mathematics	9
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		49

Sophomore Year

Fall		Units
15-112	Fundamentals of Programming and Computer Science	12
21-201	Undergraduate Colloquium	1
21-268	Multidimensional Calculus	10
or 21-269	Vector Analysis	
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		41

Spring		Units
15-122	Principles of Imperative Computation	10
21-261	Introduction to Ordinary Differential Equations	10
21-355	Principles of Real Analysis I	9
or 21-455	Intermediate Real Analysis I	
38-230	ENGAGE in Wellness: Looking Inward	1
xx-xxx	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
		48

Junior Year

Fall		Units
21-325	Probability	9
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
21-356	Principles of Real Analysis II	9
or 21-456	Intermediate Real Analysis II	
38-330	ENGAGE in Wellness: Looking Outward	1
xx-xxx	Nontechnical Elective	9
xx-xxx	Free Elective	9
		37

Spring		Units
21-369	Numerical Methods	12
xx-xxx	Mathematics Elective	9
xx-xxx	Depth Elective	9
xx-xxx	Science and Society Course	
xx-xxx	Cultural/Global Understanding Elective	9
xx-xxx	Free Elective	9
		48

Senior Year

Fall		Units
xx-xxx	Mathematics Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	Depth Elective	9
38-110	ENGAGE in Service [1]	1
38-220	ENGAGE in the Arts [1]	2
38-430	ENGAGE in Wellness: Looking Forward	1
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		49

Spring		Units
xx-xxx	Mathematics Elective	9

xx-xxx	Depth Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Minimum number of units required for degree: 360

B.A. in Mathematical Sciences

Mathematical Sciences Courses (required)

21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-201	Undergraduate Colloquium	1
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-259	Calculus in Three Dimensions	9
or 21-266	Vector Calculus for Computer Scientists	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-325	Probability	9
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	

Forty-five units of Mathematical Sciences electives (at the 21-300 level or above; or 21-270 or 21-292).

Twenty-seven units of Mathematical Sciences (at the 21-300 level or above; or 21-270 or 21-292), or Computer Science (at the 15-200 level or above; or Physics (at the 33-300 level or above; or Statistics (at the 36-300 level or above; and have at least 36-225 as a prerequisite) electives.

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units)

[1] Students must register for this course no later than their penultimate semester. But, work for this course can be begun in any semester prior to registration.

Additional Major Requirements

All concentrations within the B.S. in Mathematical Sciences are available as an additional major to students majoring in other departments. The requirements for the additional majors are the same as those for the B.S degrees, except that the MCS General Education requirements are waived.

In order to avoid double-counting issues, students are encouraged to consult with their degree advisor as well as their additional major advisor.

Please visit the Department of Mathematical Sciences Undergraduate FAQ website (https://www.cmu.edu/math/undergrad/faq.html) (under "Admissions") for further details

The Minor in Mathematical Sciences

The Minor includes six courses. 21-127 Concepts of Mathematics is a prerequisite for 21-228 and recommended for 21-241 . The minimum preparation required for 21-355 Principles of Real Analysis I is 21-122 and 21-127 or equivalent courses. Please see below if you are a Computational Finance major.

21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
or 15-151	Mathematical Foundations for Computer Science	
21-228	Discrete Mathematics	9-12
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-355	Principles of Real Analysis I	9
21-3xx	Mathematical Sciences Elective	
21-3xx	Mathematical Sciences Elective	

To avoid excessive double counting, the two Mathematical Sciences Electives may not also count toward the student's major.

Computational Finance majors who declare a minor in Mathematical Sciences should take the following six courses:

Required courses are:

21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
or 15-151	Mathematical Foundations for Computer Science	
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-355	Principles of Real Analysis I	9
21-325	Probability	9
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	

Nine units of Mathematical Sciences Electives, to be chosen from the following list:

21-300	Basic Logic	9
21-301	Combinatorics	9
21-329	Set Theory	9
21-373	Algebraic Structures	9
21-484	Graph Theory	9

**Students who take 21-325 (or 15-259 or 36-218) to fulfill their BSCF requirements should take an additional 21-3xx elective to avoid excessive double counting.*

The Minor in Discrete Mathematics and Logic

This minor develops the fundamentals of discrete mathematics and logic necessary to understand the mathematical foundations of many computer related disciplines. Required courses are:

21-228	Discrete Mathematics [1]	9-12
or 15-251	Great Ideas in Theoretical Computer Science	
21-300	Basic Logic	9
or 15-317	Constructive Logic	
21-301	Combinatorics	9

[1] 21-127 Concepts of Mathematics is a prerequisite for 21-228.

Twenty-seven units of Mathematical Sciences Electives, to be chosen from the following two groups (at least nine units from each group).

Logic		
21-321	Interactive Theorem Proving	9
21-329	Set Theory	9
21-400	Intermediate Logic	9
21-602	Introduction to Set Theory I	12
21-603	Model Theory I	12
80-315	Modal Logic	9
80-411	Proof Theory	9
80-413	Category Theory	9
Algebra and Discrete Mathematics		
21-341	Linear Algebra	9
21-373	Algebraic Structures	9
21-374	Field Theory	9
21-441	Number Theory	9
21-484	Graph Theory	9

21-610	Algebra I	12
21-701	Discrete Mathematics	12

The Honors Degree Program

This demanding program qualifies the student for an additional degree, the Master of Science in Mathematical Sciences. Admission to the Honors Degree Program is selective and interested students should apply for admission during their junior year. In the application process, the Department will hold to the same high standards which apply to admission to any graduate program. Applicants are not absolutely required to have taken the Mathematical Studies courses and may be admitted on the basis of exceptionally strong performance in non-honors mathematics courses or of accomplishments in research. Applicants are expected to have completed the Mathematical Studies sequences in Algebra and Analysis or 21-355/21-356 and 21-373/ 21-341 prior to application.

In order to complete the Honors Degree Program, students must complete five mathematics graduate courses with grades of B- or better and write an honors thesis. At the time of admission, students will declare a timetable on which they plan to take the graduate courses, do the research required for the thesis, and write up their work: this timetable can naturally be adjusted as required. At most, one of these five graduate courses may be applied towards the student's bachelor degree program.

At least three graduate courses must come from the list of Basic Examinations courses found at www.cmu.edu/math/grad/phd/requirements.html (https://www.cmu.edu/math/grad/phd/requirements.html).

Currently these are listed as:

- General Topology (21-651)
- Functional Analysis (21-640)
- Measure and Integration (21-720)
- Probability (21-721)
- Discrete Mathematics (21-701)
- Probabilistic Combinatorics (21-737)
- Set Theory (21-602)
- Algebra (21-610)
- Model Theory (21-603)
- Differential Equations (21-632)

By special permission of the department, one graduate course with sufficient mathematical content offered in another department may be counted. The honors thesis may either be research-based or expository: expository theses must be at a high mathematical level, at least that of a second-year graduate course. Students should plan on finding a thesis advisor by the end of their junior year. Students are required to take the Masters Degree Reading and Research (21-901) course during their senior year, subject to the following conditions:

1. Students must complete a minimum of 15 units of 21-901 to earn the MS degree.
2. Students who have not defended their thesis by the Add Course Deadline during each of their last two semesters must register for a minimum of 3 units of 21-901 for that semester.
3. Students may not overload more than 66 units while taking 21-901.

The Master of Science degree in Mathematical Sciences may be earned together with a Bachelor of Science from another department.

Faculty

NOHA ABDELGHANY, Assistant Teaching Professor – Ph.D.,, Western Michigan University; Carnegie Mellon, 2022–

THERESA ANDERSON, Assistant Professor – Ph.D., Brown University; Carnegie Mellon, 2022–

JEREMY AVIGAD, Professor – Ph.D., University of California, Berkeley; Carnegie Mellon, 1996–

THOMAS BOHMAN, Professor – Ph.D., Rutgers University; Carnegie Mellon, 1998–

BORIS BUKH, Professor – Ph.D., Princeton University; Carnegie Mellon, 2012–

CLINTON CONLEY, Associate Professor – Ph.D., University of California Los Angeles; Carnegie Mellon, 2014–

GÉRARD CORNUÉJOLS, IBM University Professor of Operations Research – Ph.D., Cornell University; Carnegie Mellon, 1978–

JAMES CUMMINGS, Professor – Ph.D., Cambridge University; Carnegie Mellon, 1996–

HASAN DEMIRKOPARAN, Teaching Professor of Mathematics – Ph.D., Michigan State University; Carnegie Mellon, 2005–

TIMOTHY FLAHERTY, Associate Teaching Professor – Ph.D., University of Pittsburgh; Carnegie Mellon, 1999–

IRENE FONSECA, Kavčić-Moura University Professor of Mathematics – Ph.D., University of Minnesota; Carnegie Mellon, 1987–

FLORIAN FRICK, Associate Professor – Ph.D., Technical University of Berlin; Carnegie Mellon, 2018–

ALAN FRIEZE, Orion Hoch, S 1952, University Professor of Mathematical Sciences – Ph.D., University of London; Carnegie Mellon, 1987–

IRINA GHEORGHICIUC, Associate Teaching Professor – Ph.D., University of Pennsylvania; Carnegie Mellon, 2007–

RAMI GROSSBERG, Professor – Ph.D., Hebrew University of Jerusalem; Carnegie Mellon, 1988–

DAVID HANDRON, Associate Teaching Professor – Ph.D., Rice University; Carnegie Mellon, 1999–

JASON HOWELL, Teaching Professor – Ph.D., Clemson University; Carnegie Mellon, 2017–

WILLIAM HRUSA, Professor – Ph.D., Brown University; Carnegie Mellon, 1982–

GAUTAM IYER, Professor – Ph.D., University of Chicago; Carnegie Mellon, 2009–

GREGORY JOHNSON, Associate Teaching Professor – Ph.D., University of Maryland; Carnegie Mellon, 2009–

NIRAJ KHARE, Assistant Teaching Professor – Ph.D., Ohio State University; Carnegie Mellon, 2014–

DAVID KINDERLEHRER, Alumni Professor of Mathematical Sciences – Ph.D., University of California at Berkeley; Carnegie Mellon, 1990–

DMITRY KRAMKOV, Mellon College of Science Professor of Mathematical Finance – Ph.D., Steklov Mathematical Institute; Carnegie Mellon, 2000–

MARTIN LARSSON, Professor – Ph.D., Cornell University; Carnegie Mellon, 2019–

JOHN LEHOCZKY, Thomas Lord University Professor of Statistics – Ph.D., Stanford University; Carnegie Mellon, 1969–

GIOVANNI LEONI, Professor – Ph.D., University of Minnesota; Carnegie Mellon, 2002–

PO-SHEN LOH, Professor – Ph.D., Princeton University; Carnegie Mellon, 2009–

JOHN MACKEY, Teaching Professor – Ph.D., University of Hawaii; Carnegie Mellon, 2003–

ROBIN NEUMAYER, Assistant Professor – Ph.D., The University of Texas at Austin; Carnegie Mellon, 2021–

CLIVE NEWSTEAD, Assistant Teaching Professor – PhD, Carnegie Mellon University; Carnegie Mellon, 2018–

DAVID OFFNER, Associate Teaching Professor – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2019–

MARION OLIVER, Teaching Professor – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2004–

WESLEY PEGDEN, Associate Professor – Ph.D., Rutgers University; Carnegie Mellon, 2013–

AGOSTON PISZTORA, Associate Professor – Ph.D., ETH Zurich; Carnegie Mellon, 1996–

HAYDEN SCHAEFFER, Associate Professor – Ph.D., University of California at Los Angeles; Carnegie Mellon, 2015–

ERNEST SCHIMMERLING, Professor – Ph.D., University of California at Los Angeles; Carnegie Mellon, 1998–

DEJAN SLEPČEV, Professor & Associate Department Head – Ph.D., University of Texas at Austin; Carnegie Mellon, 2006–

RICHARD STATMAN, Professor – Ph.D., Stanford University; Carnegie Mellon, 1984–

PRASAD TETALI, Alexander M. Knaster Professor & Department Head – Ph.D., New York University; Carnegie Mellon, 2021–

IAN TICE, Associate Professor – Ph.D., New York University; Carnegie Mellon, 2012–

KONSTANTIN TIKHOMIROV, Associate Professor – Ph.D., University of Alberta; Carnegie Mellon, 2022–

TOMASZ TKOCZ, Associate Professor – Ph.D., University of Warwick; Carnegie Mellon, 2017–

NOEL WALKINGTON, Professor – Ph.D., University of Texas at Austin; Carnegie Mellon, 1989–

ZELEALEM YILMA, Associate Teaching Professor – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2015–

MICHAEL YOUNG, Associate Dean for Diversity, Equity and Inclusion & Associate Professor – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2021–

Emeriti Faculty

PETER ANDREWS, Professor Emeritus – Ph.D., Princeton University; Carnegie Mellon, 1963–

MANUEL BLUM, University Professor Emeritus – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 1999–

DEBORAH BRANDON, Associate Teaching Professor Emeritus – Ph.D., Carnegie Mellon University; Carnegie Mellon, 1991–

ROY NICOLAIDES, Professor Emeritus – Ph.D., University of London; Carnegie Mellon, 1984–

DAVID OWEN, Professor Emeritus – Ph.D., Brown University; Carnegie Mellon, 1967–

ROBERT PEGO, Professor Emeritus – Ph.D., University of California at Berkeley; Carnegie Mellon, 2004–

JACK SCHAEFFER, Professor Emeritus – Ph.D., Indiana University; Carnegie Mellon, 1983–

ROBERT SEKERKA, University Professor Emeritus – Ph.D., Harvard University; Carnegie Mellon, 1969–

STEVEN SHREVE, University Professor Emeritus – Ph.D., University of Illinois; Carnegie Mellon, 1980–

SHLOMO TA'ASAN, Professor Emeritus – Ph.D., Weizmann Institute; Carnegie Mellon, 1994–

LUC TARTAR, University Professor of Mathematics Emeritus – Ph.D., University of Paris; Carnegie Mellon, 1987–

RUSSELL WALKER, Teaching Professor Emeritus – D.A., Carnegie Mellon University; Carnegie Mellon, 1984–

WILLIAM WILLIAMS, Professor Emeritus – Ph.D., Brown University; Carnegie Mellon, 1966–